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2-D and 3-D elastic modeling with shared seismic models

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Summary

Several elastic models, both 2-D and 3-D, are being built for use in calculating synthetic elastic seismic data. The models will be made available to the research community, along with the synthetic data that are being calculated from them. These shared models have been proposed or contributed by participants in a collaborative industry, national laboratory, and university research project. The purpose of the modeling is to provide synthetic data to better understand elastic wave propagation and the effects of structural and stratigraphic complexities. The 2-D models are easier to design and change and synthetic calculations can be run relatively quickly in them. It will be possible to alter their layer properties and calculate time-lapse data sets from them. Field data will be available to accompany many of the 2-D models. 3-D models are more realistic, but more difficult to design and change. They also require considerably more computing resources to calculate synthetic data from them. A new 3-D model is being designed, and will be used for computing synthetic elastic data.

Introduction

Elastic wave propagation effects are increasingly important to understand, as greater importance is placed on accurately processing and imaging seismic data from areas where complex structures produce significant wave conversions. In addition, there is increasing interest in collecting and processing multi-component seismic data and on accurate imaging from it. The dramatic increase in computing power in the past several years allows carrying out simulations that are more realistic than ever before. While each research organization has its own objectives and concerns with models and imaging, there is considerable benefit in building and computing synthetic data with shared seismic models. The importance of the insights that can be learned from shared models is underscored by the popularity of the synthetic data sets from the 2-D Marmousi model and the 3-D SEG-EAEG salt model. These models represented the state of the art in seismic modeling 5 to 10 years ago and data from them continues to be used in many presentations at the SEG and EAGE meetings.

Understanding elastic wave propagation requires high quality elastic test data sets, which are not generally available. In collaboration with industry participants, we are designing new 2-D and 3-D models that will provide synthetic data suitable for testing and calibration of current elastic and converted wave processing and imaging methods.

In the early 1990's, several 2-D and 3-D acoustic seismic models were designed to test acoustic imaging, velocity analysis, and other processing technologies, such as AVO. The 2-D Marmousi model (Versteeg, 1994) and the 3-D SEG/EAEG salt model (Aminzadeh *et al.* 1997) were among the most widely used models. Those models, and the synthetic seismic data computed from them were shared with all interested researchers. That sharing facilitated building up a huge collective pool of understanding of the strengths and weaknesses of processing algorithms, velocity estimation methods, imaging methods, and acquisition designs.

This modeling effort intends to make similar contributions to elastic modeling through the use of shared models and synthetic data. Larsen *et al.* (2001) showed the promise and feasibility of carrying out realistic 3-D elastic calculations in a complex 3-D elastic model (an elastic version of the SEG-EAEG salt structure). Full elastic modeling with realistic modeling parameters requires considerable computing and cannot yet be done routinely. Compromises, such as reducing the size of the model, or reducing the frequency of the computed data, can drastically reduce the computing needed and make this type of modeling more routine.

Modeling Approach

This work is being done through a collaborative project that includes oil and gas industry participants, national laboratories, and universities. The modeling itself has two parts, one shorter-term, devoted to 2-D modeling, the other longer term, devoted to 3-D modeling. For the 2-D modeling, project participants have proposed ten 2-D models, all but one of which would have accompanying field data sets. For the 3-D modeling, we have focussed on constructing a new 3-D model that is more versatile than the SEG-EAEG salt model.

<u>2-D Models.</u> The 2-D models that have been proposed include offshore as well as onshore structures, and pose a variety of wave propagation problems. The first 2-D model that has been built is derived from the Marmousi model, which is a model of a structure from offshore Angola. The Institut Français du Pétrôle coordinated construction of it, and the synthetic seismic data from it have served as a benchmark for testing 2-D velocity analysis and imaging algorithms for many years

(Versteeg, 1994). An elastic model, which we term "Marmousi-2" was constructed from the original Marmousi model. Martin et al, (2002) describe the important features of Marmousi-2. Summarize them briefly, the lateral extent of the original Marmousi model was nearly doubled, to allow for longer source-receiver offsets. Each layer of the model was assigned a particular lithology (sand, shale, marl, salt, and water) and fluid content. Compared to the original model, Marmousi-2 has more hydrocarbons in both structurally simple and complex areas. Stratigraphic features, including channels and a layer with zero P-wave impedance contrast were added. An additional 500 m of water was added at the top of the model to allow for use of ocean bottom cable acquisition. P wave velocities and densities were taken from the original Marmousi model, except for salt velocities, which seemed too high, and were reduced slightly to 4500 m/s. The Vs, and modified density were determined through fluid-substitution relationships. Figure 1 shows the compressional (Vp) and shear (Vs) velocities of the Marmousi-2 model. Numerical modeling (finite-difference) calculations have been carried out from a few shots; a full survey will be calculated from this model. Figure 2 shows the positions of two shots and wavefield snapshots from them at two time intervals. Note the large number of reverberations that are present in the wavefield at only 1 s, particularly for shot 2, and even greater number of large amplitude reverberations in the wavefield at 1.5 s

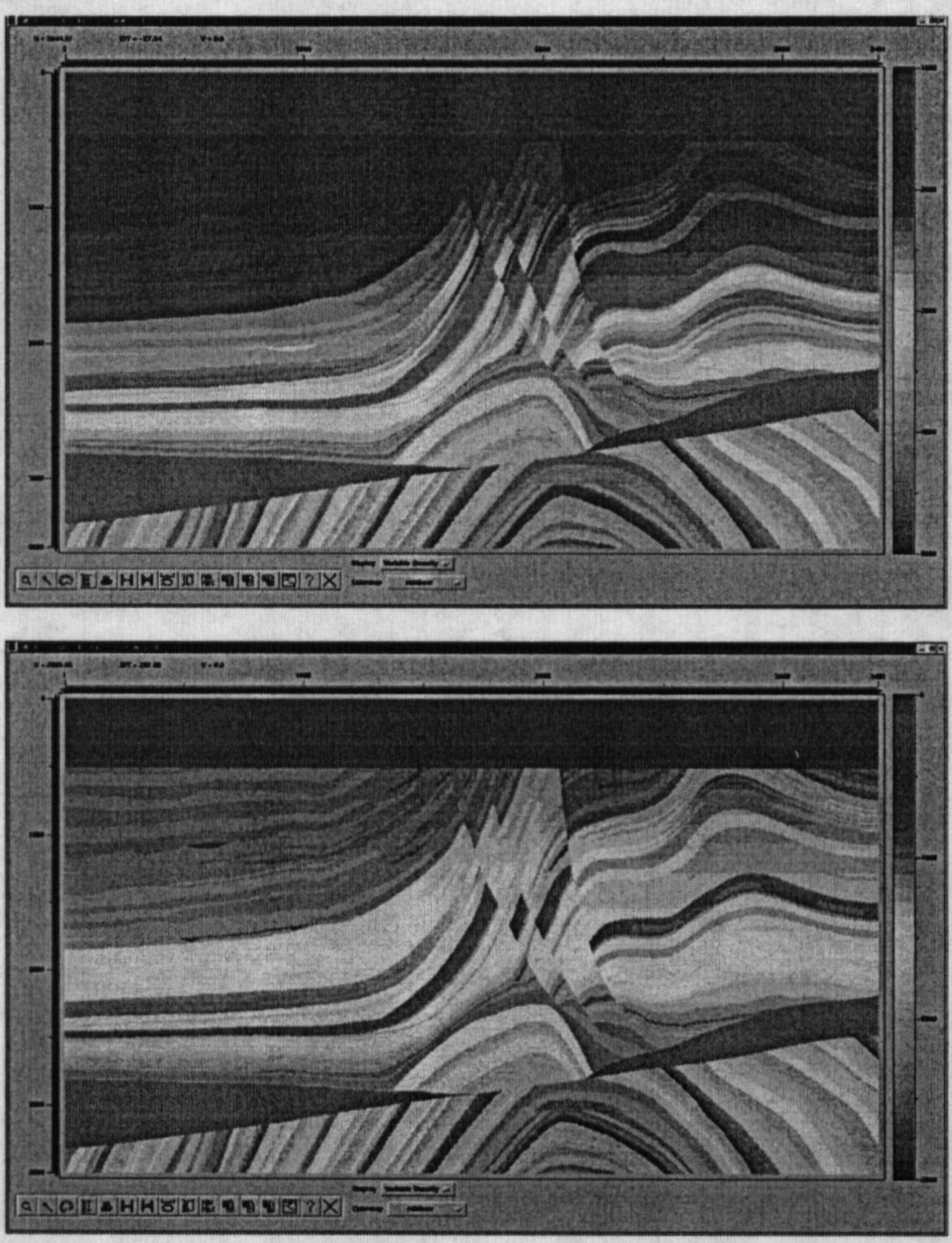

Figure 1. P wave (top) and S wave (bottom) velocities in the Marmousi-2 model. The plots use different velocity scaling, with the corresponding color bars at the right of each plot. The P wave color bar runs from 1,000 m/s (purple) to 5,000 m/s (red). The S wave color bar runs from 0 (purple) to 3,000 m/s (red). Velocities are difficult to distinguish in black and white plots; figures are best viewed in their color form on the CD-ROM.

Several other 2-D models, based on field examples, are in various stages of completion. A model from the Ft. Worth basin is nearly complete and will have accompanying field data. Other models being considered include several from the Gulf of Mexico, both shallow and deep water, and two crustal-scale surveys. By including these crustal-scale models in this work we hope to emphasize the similarities of the data and the problems being studied by researchers in industry and academia. The academic geophysics community is increasingly concerned with crust and upper mantle structure problems that require analysis and imaging methods similar to those in routine use by industry. We hope that this project will help academic researchers better justify the increased cost of collecting the denser-sampled surveys that are amenable to exploration-style processing.

3-D Models. The leading candidate for a new 3-D model is one that will be adapted from a model designed by a joint venture of several oil companies. That model was built for multiple suppression and subsalt illumination studies at the Gulf of Mexico shelf edge. We will modify the model by adding stratigraphic features, such as channels and fans along the deformed interfaces, which should expand the usefulness of the model and model data. In addition to providing a test bed for seismic imaging and velocity analysis, the calculated data will be used to calibrate and validate current seismic attribute technology, including coherence, dip/azimuth, spectral decomposition, impedance inversion and AVO. Calculation of synthetic data from the selected models will exploit the computational resources provided by the national laboratories and will use the finite-difference modeling algorithm described by Larsen and Grieger (1998). This is a very large model, and carrying out the numerical simulations will require careful choice of modeling parameters. We expect that the project's industry participants will have a large role in deciding these modeling parameters.

While the new 3-D model is being prepared, we are continuing to carry out 3-D elastic simulations with an elastic version of the SEG-EAEG salt model described by House *et al.* (2000). The calculations use a simulated explosive source, with a Ricker wavelet. Most of the simulations have been done with an 8 Hz central frequency source. These calculations required about 170 cpu-hours per shot. One shot was also run with a 15 Hz central frequency source, and required about 3,360 cpu-hours.

Two receiver arrays are used. One is a simulated multi-component Ocean Bottom Cables (OBC), the other simulates a traditional marine streamer survey. Two sets of OBC's are used- one aligned along the X direction in the model, the other along the Y direction. The spacing between adjacent cables is 996 m, and receivers in each cable are 24 m apart. The marine streamer survey uses 8 streamers, with a total of 141 receivers each, spaced 24 m apart. One simulation was run with a dense grid of single-component (marine streamer type) receivers at receiver spacing of 24 m in both X and Y directions.

Full 3-D elastic simulations have been run for a total of 120 shots; some shots were run as acoustic-only calculations as well as full elastic calculations. Figure 3 shows a plot of the SEG-EAEG salt structure, and the positions of completed and planned shots. Shots colored red in the figure are those that the 3-D elastic calculations have been completed for. Figure 4 shows shot records from the shot that is circled in Figure 3. The plots show compressional (P) wave potential (left) and shear (S) wave potential (right). The P wave plot (left) shows traces that would have been recorded by hydrophones. Since this was an elastic simulation, the effects of wave conversions are included. The S wave section shows quite different events, which emphasizes the importance and usefulness of taking account of elastic wave propagation in processing and imaging, especially if correct amplitudes are important.

Data from these simulations will be made available on a project web site.

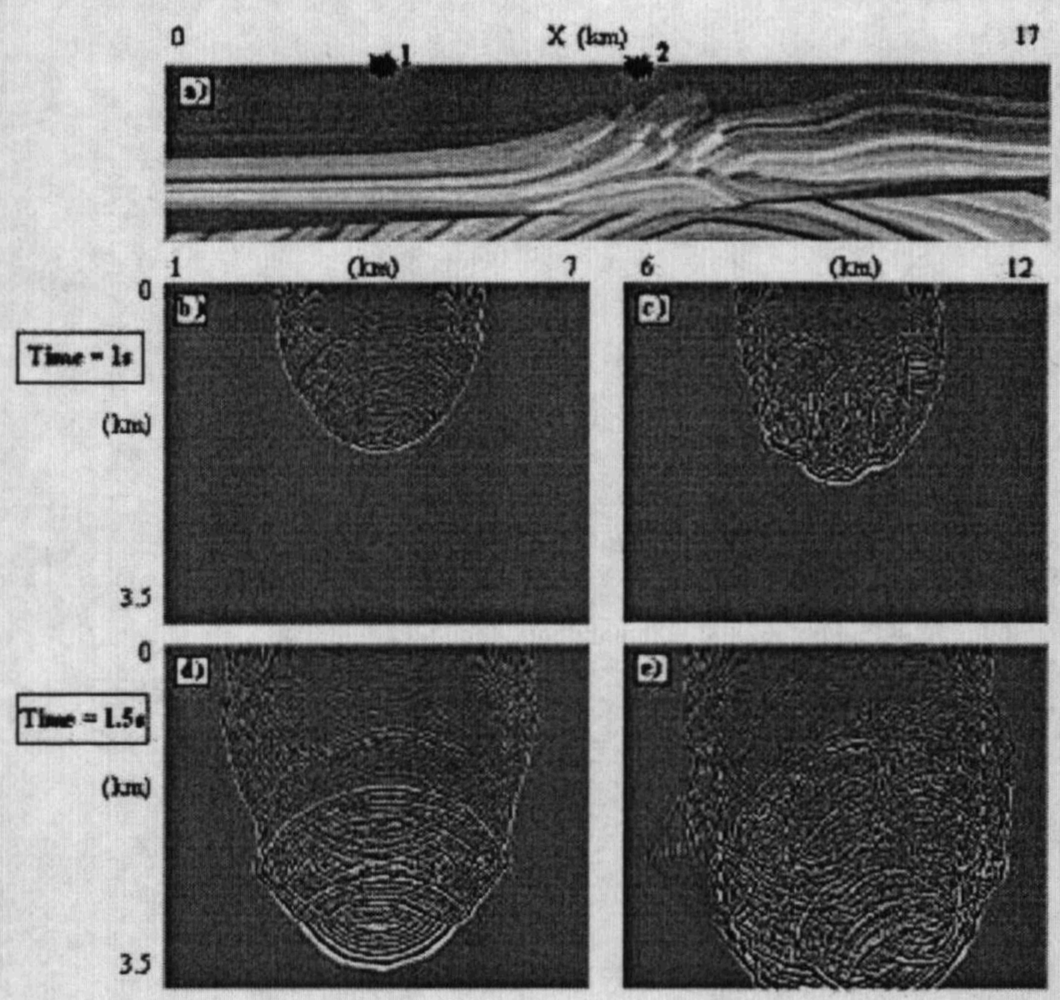

Figure 2. Marmousi-2 model and wavefield snapshots. The top plot (a) shows the positions of the two shots (labelled 1 and 2). The middle plots (b and c) are snapshots of the wavefield after 1 s for shots 1 and 2, respectively. The bottom plots (d and e) are snapshots at 1.5 s for shots 1 and 2, respectively.

Conclusions

An industry, national laboratory, university collaboration is building 2-D and 3-D geological models to carry out full elastic wave simulations in both 2-D and 3-D. The models, the simulated data, and accompanying field data (from several 2-D models) will all be shared with other researchers. This work aims particularly to obtain models and data sets that will provide calibration of imaging technologies, as well as other types of processing, such as AVO, polarization filtering, tomography, multicomponent seismic analysis, converted wave tomography and seismic attribute analysis. One 2-D model, termed Marmousi-2 is complete, and initial test data have been calculated from it. Another 2-D model (Ft. Worth basin) is nearly complete. Work on other 2-D models has started. The availability of field data to accompany many of the 2-D models is being discussed with companies, with the goal of making the field data available along with the models and synthetic seismic data. A new 3-D elastic model of a simulated deep-water salt structure is also planned. This will take much more time to complete than the 2-D models. While the new model is developed, simulations have continued using an existing 3-D model, the SEG-EAEG salt structure. An elastic version of the salt structure is being used for 3-D elastic simulations, with both simulated Ocean Bottom Cables and traditional marine streamers. Data from these simulations will be made available via web-access.

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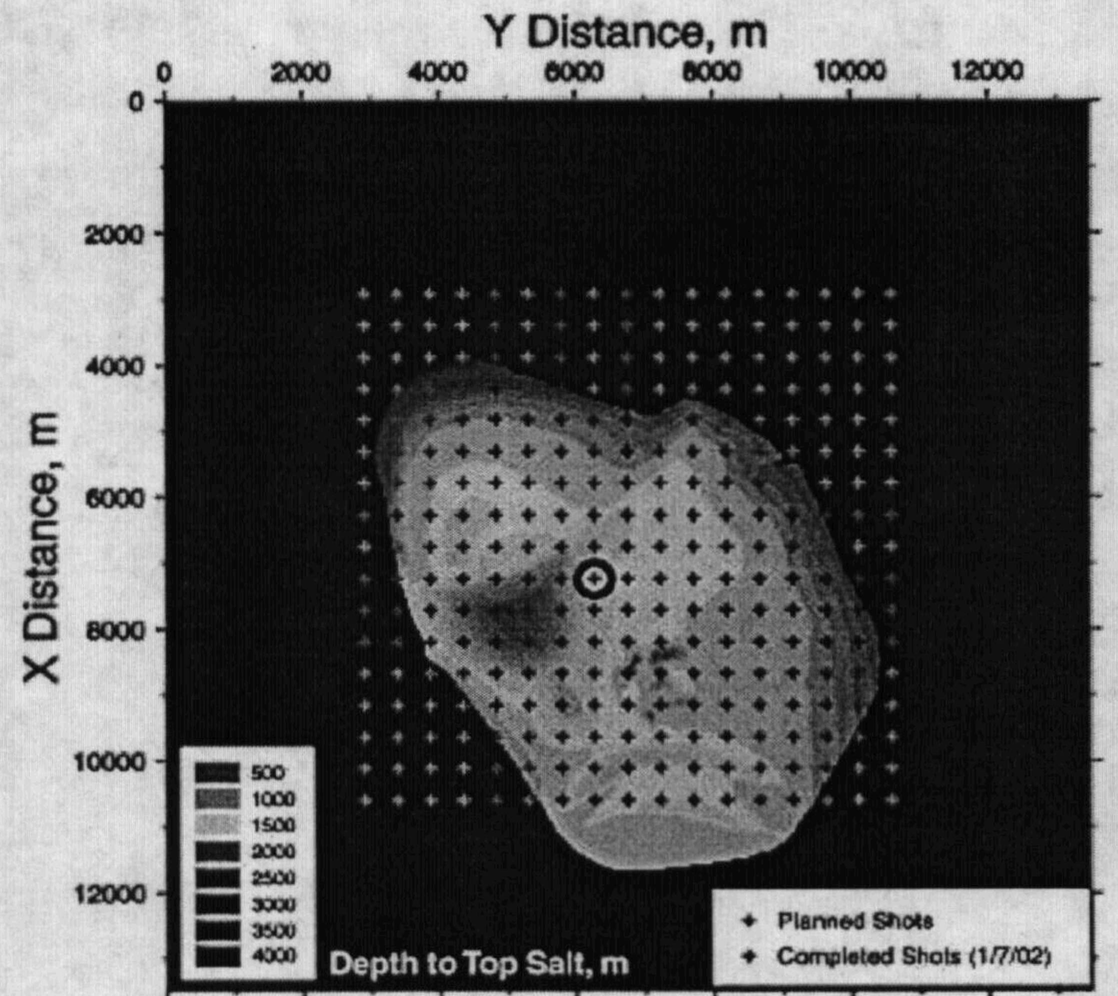

Figure 3. Plot of depth to the top of the salt body in the SEG-EAEG salt structure, with the positions of shots superposed. A 17 by 17 grid of shot positions (crosses) was defined; 3-D elastic simulations have been completed for the 120 shots shown in red. Shot records from the shot circled are shown in Figure 4

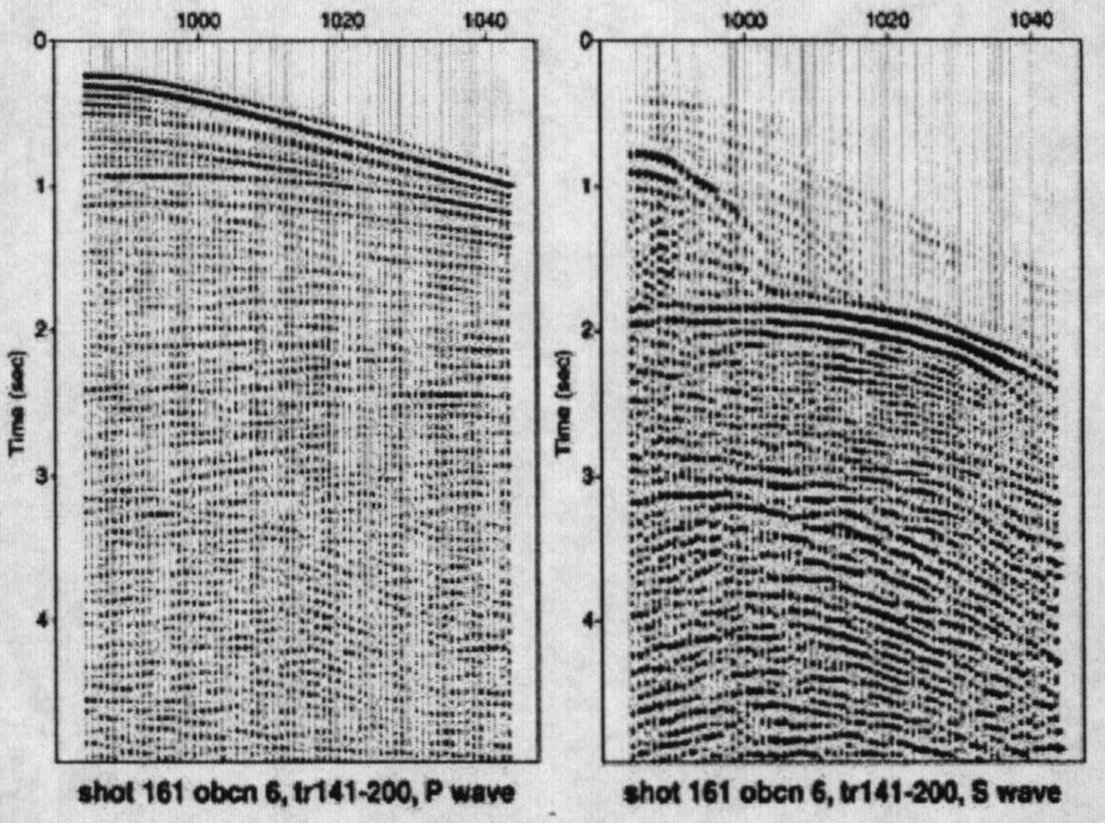

Figure 4. Shot records from the shot circled in Figure 3. Left plot shows P wave potential (as would be recorded by hydrophones); right plot shows S wave potential. The large amplitude event at about 2 s in the right plot is the converted wave reflection from the base of the salt. The P wave reflection from top of salt is at about 1 s in the left plot.